Method of Test

FIELD MOISTURE - DENSITY RELATIONSHIPS

DOTD Designation: TR 415M - 99

METRIC VERSION

METHOD A - DETERMINATION BY FAMILY OF CURVES

I. Scope

A. This method of test is designed to determine the relationship between the moisture content of soils or soil-aggregate mixtures with 60% or less siliceous aggregate by wet mass retained on the 4.75 mm sieve (raw or lime treated) and the resulting density when the material is compacted as specified in this procedure. The moisture-density relationship of the material is determined though the use of the Family of Moisture-Density Curves (Figure A-1) and a one-point proctor. This method is to be used as permitted by DOTD TR 418.

B. Reference Documents
   1. DOTD TR 418 - Moisture-Density Relationships
   2. DOTD TR 403 - Determination of Moisture Content
   3. AASHTO M 92 - Wire Cloth Sieves for Testing Purposes
   4. DOTD S 401 - Sampling Soils

II. Apparatus

A. **Mold**
   1. A cylindrical metal mold having a capacity of 0.000944 m^3 manufactured with an internal diameter of 101.60 ±0.41 mm and a height of 116.43 ±0.13 mm, and with a detachable collar approximately 64 mm in height, which can be fastened firmly to a base plate.
   2. Molds are to be replaced when any diameter is more than 102.21 mm or the height is less than 115.57 mm at any point.

B. **Compactive device**
   1. Automatic Rammer
      a. A metal 2.495±0.023 kg rammer, with a sector striking face that has an area equal to that of 50.80 mm diameter face for use with a 101.60 mm inside diameter mold and arranged to control the height of drop to 305±2 mm
      b. Alternate - a metal 2.495±0.023 kg rammer, with a sector striking face that has an area equal to that of a 50.80 mm diameter face for use with a 101.60 mm inside diameter mold and arranged to control the height of drop to 457±2 mm
   2. Manual Rammer - a metal 2.495±0.023 kg rammer with a circular striking face with a diameter of 50.80 mm and arranged to control the height of drop to 305±2 mm.

C. **Compaction block** - a stable block or pedestal composed of portland cement concrete with a smooth, level surface on the top and bottom, with both surfaces parallel, weighing a minimum of 90 kg. The compaction block may be obtained from the district laboratory.

D. **Straightedge** - steel straightedge, approximately 300 mm long.

E. **Balance or scale** - having a capacity of 10 kg or more and sensitive to 5 g.

F. **Sieve** - a 4.75 mm sieve conforming to AASHTO M 92.

G. **Tools**
   1. **Mixing pans** - with appropriate covers.
   2. **Spoons.**
   3. **Pointed trowel.**
   4. **Spatula** - or large suitable mechanical device for thoroughly mixing the soil with water.
   5. **Large screwdriver** - to remove material from mold.

H. **Water**.

I. **Containers** - 4-liter friction top cans with tops.

J. **Density and Moisture Content Worksheet,** DOTD Form No. 03-22-0750. (Figure A-2)

III. Sample

In accordance with DOTD S 401, obtain a representative sample of the material in field condition, such that after preparation, approximately 3 kg of material passing the 4.75 mm sieve is produced for each one-point proctor.

Note A-1: *If the sample contains aggregate, obtain approximately 7 kg for each one-point proctor.*

IV. Procedure

A. Determine the total wet mass of the sample (a) and record on the worksheet.

B. Screen total sample over the 4.75 mm sieve, forcing all material except aggregate through the sieve.

Note A-2: *If the aggregate retained on the No. 4 sieve is not siliceous, do not continue with this test method. Perform the test in accordance with the appropriate method of DOTD TR 418.*

C. Determine wet mass of the fraction retained on the 4.75 mm sieve (b) and record on the worksheet.

D. In accordance with step V.A., determine the percent retained on the 4.75 mm sieve based on the total wet mass of the sample (c) and record on the worksheet.

E. Compact the test specimen using the rammer, using material passing the 4.75 mm sieve at a moisture content that falls within the designated area on the Family of Curves.

1. If mold requires an attachable base plate, attach base plate. Weigh mold and base plate (e) and record on the worksheet.

Note A-3: *When using a mold without an attachable base plate, place wax paper on the compactor base. Weigh the mold and record the weight as **e** on the worksheet. Place the mold over the wax paper and secure the mold to the compactor base.*

2. Attach the collar to the mold.
3. Thoroughly mix the material to be placed in the mold.
4. Place a quantity of the material in the mold in an even layer that will yield slightly more than 1/3 the volume of the mold after compaction.
5. Use a pointed trowel to rearrange particles, filling voids in the loose material without compacting the material, to a uniform lift thickness.
6. Rest the rammer on top of the layer to be compacted. Compact the layer using 25 blows with the 2.495 kg rammer from a 305 mm drop (alternate 17 blows with a 2.495 kg rammer from an 457 mm drop).
7. Note the height of the compacted material. If the compacted layer is not 1/3 the height of the mold, correct for any deviation by adjusting the quantity of material used for the subsequent layer.
8. Repeat steps IV.E.4 - 7 for two more layers.

F. After the third layer has been compacted, place the mold, base plate (if applicable), and compacted specimen in a pan.

G. Tap the collar with the straightedge to loosen material bond and remove the collar from the mold, without twisting or causing shear stress to the molded specimen.

H. Note the height of the compacted test specimen.

1. If the compacted material is greater than 6 mm above the top of the mold, remix it with the original material and repeat the test.
2. If the compacted material is below the rim of the mold, remove all the material from the mold, remix it with the original material and repeat the test.

I. Keeping the mold, base plate (if applicable) and specimen in the pan, trim the specimen even with the top of the mold, using the straightedge. Fill any depressions with the trimmed material. After the depressions are filled, smooth the top of the cylinder with the straightedge even with the top of the mold.

J. Determine the mass of the mold and the specimen (d) and record on the worksheet.

K. Determine the wet density of the specimen (g) in accordance with step V.B. Record on the worksheet.

L. Detach the base plate from the mold. Remove the specimen from the mold.

M. Take a representative portion from the center of the compacted specimen. Use the representative portion to determine the moisture content (k) in accordance with DOTD TR 403. Record the moisture content on the worksheet. (The entire specimen may be dried to determine the moisture content, in lieu of using a representative portion.)

N. Determine the maximum dry density and optimum moisture of the material passing the 4.75 mm sieve.

1. Plot a point on the Family of Moisture Density Curves representing the intersection of a horizontal line representing the wet density and a vertical line projected from the moisture content.
2. The point plotted in step N. 1 must fall within one of the shaded areas (zones) of the curves (either the major 1- 41 section or the supplemental a-l section).
   a. If the point does not fall within one of these shaded areas, repeat steps A - M with fresh material at a different moisture content, repeating until the point falls within a shaded area.
   b. When the point falls within the shaded area of the major section (curves 1 - 41), select and record the corresponding zone number. Then read the optimum moisture (om) and maximum dry density (pr) for that zone from the table at the upper right of the Family of Moisture Density Curves. Record these values on the worksheet. Use these values to determine the optimum moisture and maximum density of the total material in accordance with steps O and P.
   c. When the point falls within the shaded area of the supplemental section (curves a - l), increase the moisture content by at least 3% and repeat steps IV.A - M.
      (1) If the point plotted at the increased moisture content indicates that wet density remains the same or indicates a reduction in wet density, select the zone letter of the supplemental section

corresponding to the original shaded area and determine dry density and optimum moisture in accordance with step N.2.b.

(2) If the point plotted at the increased moisture content indicates an increase in wet density, repeat step IV.N.2. a. until a point falls clearly in the shaded area of the major section (curves 1 - 41). Then select the zone number from the major section and determine dry density and optimum moisture in accordance with step N.

Note A-4: *When a point does not plot clearly on a curve, yet appears to fall within the supplemental section (curves a - l), it may be necessary to use field tests to identify the type of soil and its moisture content. The supplemental section represents sandy soils. Wet sandy soils will plot on the wet side of the curves in the supplemental section and dry clayey soils will plot on the dry side of the curves in the major section.*

O. Determine the maximum dry density of the total material (PR) using one of the following methods and record on the worksheet.
  1. If the percent retained on the 4.75 mm sieve is below 5, record the maximum dry density determined in step N.
  2. If the percent retained on the 4.75 mm sieve falls in the range of 5 - 20, read or interpolate by standard methods the maximum dry density of the total material using Table 1.
  3. If the percent retained on the 4.75 mm sieve is greater than 20 and but not greater than 60, determine the maximum dry density of the total material in accordance with step V.D.

P. Determine the optimum moisture of the total material (OM) by one of the following methods and record on the worksheet.
  1. If the percent retained on the 4.75 mm sieve is below 5, record the optimum moisture determined in step N as the optimum percent moisture (OM).
  2. If the percent retained on the 4.75 mm sieve falls in the range of 5 - 60, determine the optimum moisture of the total material in accordance with step. V.E.

Note A-5: *Calculate and record values to the same degree of accuracy shown in the example on the worksheet.*

V. Calculations

A. Calculate the percent retained on the 4.75 mm sieve (c), based on total mass of the sample to the nearest 1% using the following formula:

$$c = \frac{100b}{a}$$

where:

b = mass of wet material retained on 4.75 mm sieve, g
a = total mass of sample, g
100 = constant, converts decimal format to %

example:

a = 8010 g
b = 3350 g

$$c = \frac{100 \times 3350}{8010}$$

$$= \frac{335\ 000}{8010}$$

$$= 41.82$$

$$c = 42$$

B. Calculate the wet density of the specimen.
  1. Calculate the wet mass of compacted soil (f) to the nearest 1g using the following formula. Record on the worksheet.

$$f = d - e$$

where:

d = mass of mold, base plate, and specimen, g
e = mass of mold and base plate, g

example:

d = 6130
e = 4230

$$f = 6130 - 4230$$

$$f = 1900$$

  2. Calculate the wet density of the specimen (g) to the nearest 1 g using the following formula.

$$g = \frac{f}{0.944}$$

where:

f = wet mass of compacted soil, g
0.944 = constant inclusive of the volume of the mold and a conversion factor from g/m ^{3} to kg/m^3
g = wet density of specimen, kg/m^3

example:

f = 1900

$$g = \frac{1900}{0.944}$$

$$= 2012.71$$

$$g = 2013$$

C. Calculate the moisture content of the specimen.
1. Calculate the mass of water (j) to the nearest 1 g using the following formula.

$$j = h - i$$

where:

h = mass of wet representative portion, g
i = mass of dry representative portion, g

example:

h = 626 g
i = 540 g

$$j = 626 - 540$$

$$j = 86$$

2. Calculate the moisture content of the specimen (k) to the nearest 0.1% using the following formula.

$$k = \frac{100 \times j}{i}$$

where:

j = mass of water, g
i = mass of dry soil, g

example:

j = 86
i = 540

$$k = \frac{100 \times 86}{540}$$

$$= \frac{8600}{540}$$

$$= 15.925$$

$$k = 15.9$$

D. Calculate the maximum dry density (PR) for materials with siliceous gravel in the range of 20 - 60 percent retained on the 4.75 sieve using the following formula.

$$PR = \frac{2564 \times pr \times z}{\left(\frac{c}{100} \times pr \times z\right) + \left[2564\left(1 - \frac{c}{100}\right)\right]}$$

where:

pr = maximum dry density of material passing the 4.75 mm sieve
z = correction factor based on % of material retained on the 4.75 mm sieve (see Table 2 for applicable values)
c = % retained on the 4.75 mm sieve
2564 = constant, maximum dry density of siliceous gravel based on a specific gravity of 2.564 multiplied by 1 000
100 = constant, to convert percent to a decimal

example:

pr = 1748
c = 42
z = 0.95

$$PR = \frac{2564 \times 1748 \times 0.95}{\left(\frac{42}{100} \times 1748 \times 0.95\right) + \left[2564 \times \left(1 - \frac{42}{100}\right)\right]}$$

$$= \frac{4\ 257\ 778.40}{697.45 + (2564 \times 0.58)}$$

$$= \frac{4\ 257\ 778.40}{697.45 + 1487.12}$$

$$= \frac{4\ 257\ 778.40}{2184.57}$$

$$= 1949.02$$

$$PR = 1949$$

E. Calculate the optimum percent moisture for materials with siliceous gravel retained on the 4.75 sieve in the range of 5 - 60 percent using the following formula.

$$OM = \left[\left(\frac{100 - c}{100}\right) \times om\right] + \frac{c}{100}$$

TABLE 1 - METRIC

Rows: Maximum Dry Density of Material Passing the 4.75mm Sieve (kg/m^3) (pr)

Columns: Percent Retained on the 4.75mm Sieve (c)

	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0
1520	1552	1558	1565	1571	1578	1585	1591	1598	1605	1612	1619	1626	1633	1640	1647	1655
1540	1571	1578	1584	1591	1597	1604	1611	1618	1624	1631	1638	1645	1652	1659	1666	1674
1560	1591	1598	1604	1610	1617	1624	1630	1637	1644	1650	1657	1664	1671	1678	1685	1693
1580	1611	1617	1624	1630	1637	1643	1650	1656	1663	1670	1677	1683	1690	1697	1704	1711
1600	1631	1637	1643	1650	1656	1663	1669	1676	1682	1689	1696	1702	1709	1716	1723	1730
1620	1650	1657	1663	1669	1676	1682	1688	1695	1701	1708	1715	1721	1728	1735	1742	1749
1640	1670	1676	1682	1689	1695	1701	1708	1714	1721	1727	1734	1740	1747	1754	1761	1767
1660	1690	1696	1702	1708	1714	1721	1727	1733	1740	1746	1753	1759	1766	1772	1779	1786
1680	1709	1715	1722	1728	1734	1740	1746	1753	1759	1765	1772	1778	1785	1791	1798	1804
1700	1729	1735	1741	1747	1753	1759	1765	1772	1778	1784	1791	1797	1803	1810	1816	1823
1720	1749	1755	1761	1767	1773	1779	1785	1791	1797	1803	1809	1816	1822	1828	1835	1841
1740	1768	1774	1780	1786	1792	1798	1804	1810	1816	1822	1828	1834	1841	1847	1853	1860
1760	1788	1794	1799	1805	1811	1817	1823	1829	1835	1841	1847	1853	1859	1865	1872	1878
1780	1808	1813	1819	1825	1830	1836	1842	1848	1854	1860	1866	1872	1878	1884	1890	1896
1800	1827	1833	1838	1844	1850	1855	1861	1867	1873	1878	1884	1890	1896	1902	1908	1914
1820	1847	1852	1858	1863	1869	1874	1880	1886	1891	1897	1903	1909	1914	1920	1926	1932
1840	1866	1872	1877	1883	1888	1893	1899	1905	1910	1916	1921	1927	1933	1939	1944	1950
1860	1886	1891	1896	1902	1907	1913	1918	1923	1929	1934	1940	1945	1951	1957	1962	1968
1880	1905	1911	1916	1921	1926	1932	1937	1942	1948	1953	1958	1964	1969	1975	1980	1986
1900	1925	1930	1935	1940	1945	1951	1956	1961	1966	1971	1977	1982	1987	1993	1998	2004
1920	1944	1949	1954	1959	1964	1969	1975	1980	1985	1990	1995	2000	2006	2011	2016	2022
1940	1964	1969	1974	1979	1983	1988	1993	1998	2003	2008	2014	2019	2024	2029	2034	2039
1960	1983	1988	1993	1998	2002	2007	2012	2017	2022	2027	2032	2037	2042	2047	2052	2057
1980	2003	2007	2012	2017	2021	2026	2031	2036	2040	2045	2050	2055	2060	2065	2070	2075
2000	2022	2027	2031	2036	2040	2045	2050	2054	2059	2064	2068	2073	2078	2082	2087	2092
2020	2042	2046	2050	2055	2059	2064	2068	2073	2077	2082	2086	2091	2096	2100	2105	2110

TABLE 1: MAXIMUM DRY DENSITY FOR SOILS WITH SILICEOUS GRAVEL ONLY

where:

c = material retained on the 4.75 mm sieve, %
om = opt. moist. of material passing the 4.75 mm sieve, from the Family of Curves, %
100 = constant

Note A-6: *Equation assumes 1.0 percent absorbed moisture in siliceous gravel retained on 4.75 mm sieve.*

example:

c = 42
om = 16.1 (from Family of Curves)

$$OM = \left(\frac{100 - 42}{100} \times 16.1\right) + \frac{42}{100}$$

$$= \left(\frac{58}{100} \times 16.1\right) + 0.42$$

$$= (0.58 \times 16.1) + 0.42$$

$$= 9.338 + 0.42$$

$$= 9.758$$

$$OM = 9.8$$

VI. Report

Report the following:

A. Maximum dry density as PR, to the nearest 1 kg/m^3
B. Optimum Percent Moisture Content as OM, to the nearest 0.1%
C. Family of Curves Zone Number

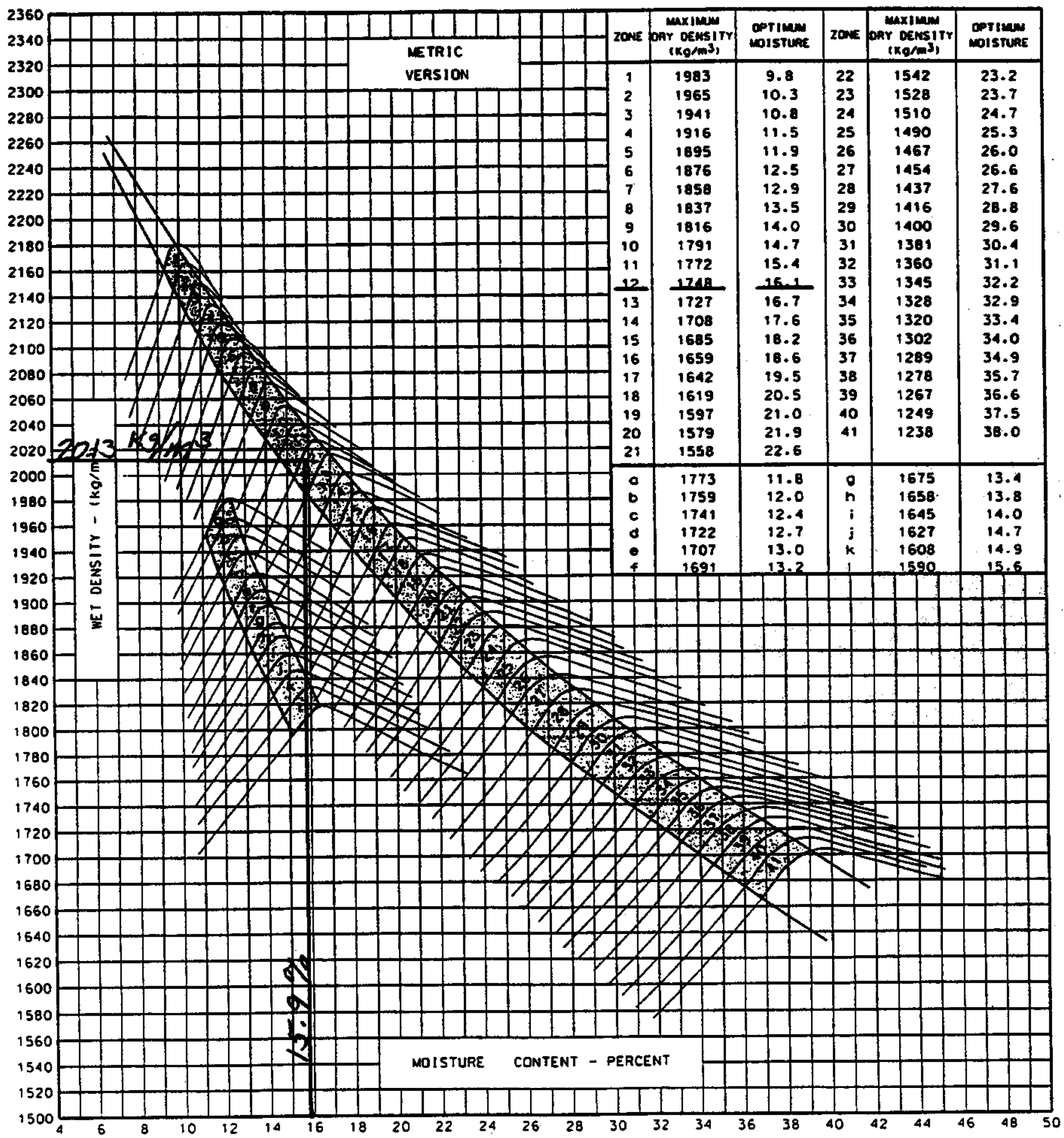
VII. Normal Test Reporting Time

The normal test reporting time is 3 hours.

TABLE 2

Table of Correction Factors (21 - 60% Siliceous Aggregate Retained on 4.75 mm Sieve)

(% retained - 4.75 mm sieve) c	correction factor z
21 - 25	0.99
26 -30	0.98
31 - 35	0.97
36 - 40	0.96
41 - 45	0.95
46 - 50	0.94
51 -55	0.92
56 -60	0.89



ZONE	MAXIMUM DRY DENSITY (Kg/m³)	OPTIMUM MOISTURE	ZONE	MAXIMUM DRY DENSITY (Kg/m³)	OPTIMUM MOISTURE
1	1983	9.8	22	1542	23.2
2	1965	10.3	23	1528	23.7
3	1941	10.8	24	1510	24.7
4	1916	11.5	25	1490	25.3
5	1895	11.9	26	1467	26.0
6	1876	12.5	27	1454	26.6
7	1858	12.9	28	1437	27.6
8	1837	13.5	29	1416	28.8
9	1816	14.0	30	1400	29.6
10	1791	14.7	31	1381	30.4
11	1772	15.4	32	1360	31.1
12	1748	16.1	33	1345	32.2
13	1727	16.7	34	1328	32.9
14	1708	17.6	35	1320	33.4
15	1685	18.2	36	1302	34.0
16	1659	18.6	37	1289	34.9
17	1642	19.5	38	1278	35.7
18	1619	20.5	39	1267	36.6
19	1597	21.0	40	1249	37.5
20	1579	21.9	41	1238	38.0
21	1558	22.6			
a	1773	11.8	g	1675	13.4
b	1759	12.0	h	1658	13.8
c	1741	12.4	i	1645	14.0
d	1722	12.7	j	1627	14.7
e	1707	13.0	k	1608	14.9
f	1691	13.2	l	1590	15.6

FAMILY OF MOISTURE-DENSITY CURVES - METRIC

For use with DOTD TR 415, Method A

Figure A-1 (Metric)
Family of Moisture - Density Curves (03-22-4050)

MATT MENU SELECTION - 07

Louisiana Department of Transportation and Development

DENSITY & MOISTURE CONTENT WORK SHEET

DOTD 03-22-0750
Metric/ English
Rev. 9/98

Metric/English (M or E) M *(Entry Field Located on Menu)*

Project No. ____ **Date Tested** ____ **Material Code** ____
Submitted By ____ **Purpose Code** ____ **Spec. Code** ____
Test Method ____ *N = Nuclear S = Sand Cone* **Item Number** ____
Station Tested ____ + ____ **Section & Test No.** ____

Location: ____ Lift No: ____ Depth of Test: ____

OM:	Optimum % Moisture Content of Total Material (TR 415 or TR 418)	OM	9.8
%FM:	Field % Moisture Content at Compaction (TR 403) *(See back for calculations)*	%FM	
P_1:	% Pulverization 19mm (3/4" SIEVE) (TR 431) *(See back for calculations)*	P_1	
P_2:	% Pulverization 4.75mm (NO.4 SIEVE) (TR 431) *(See back for calculations)*	P_2	

(TR 415) Cross Reference Test No.	Sta. No.:		**Max. Dry Density Method** 1 *(1 = TR 415A 2 = TR 415B 3 = TR 418)*
a: Total Wet Mass (Wt.) of Sample	8010		
b: Mass (Wt.) of +4.75 (+4) Material	3350		
c: % By Mass (Wt.) of 4.75 (+4)Retained (100 b/a)	42		
d: Mass (Wt.) of Mold & Soil	6130		
e: Mass (Wt.) of Mold	4230		
f: Mass (Wt.) of Compacted Soil (d - e)	1900		
g: Wet Density (f / 0.944) or (f / 2.832) or (f / 2.124) (f X 30) or (f x 10) or (f / 0.075)	2013		
h: Mass (Wt.) of Wet Soil	626		
i: Mass (Wt.) of Dry Soil	540		
j: Mass (Wt.) of Water (h - i)	86		
k: % Moisture Content (100 j/i) (TR 403)	15.9		
l: Dry Density 100g / (100 + k)			

om *(from Family of Curves)*: 16.1 pr *(from Family of Curves)*: 1748 FAMILY OF CURVES ZONE NUMBER 12

SAND METHOD (TR 401)	
SA: Mass (Wt.) of Sand in Mold	
SB: Vol. of Mold	
SC: Unit Mass (Wt.) of Sand (SA/SB)	
SD: Orig. Mass (Wt.) of Sand	
SE: Final Mass (Wt.) of Sand	
SF: Mass (Wt.) of Sand in Cone (SD-SE)	
SG: Orig. Mass (Wt.) of Sand	
SH: Final Mass (Wt.) of Sand	
SI: Mass (Wt) of Sand in Cone & Hole (SG-SH)	
SJ: Mass (Wt.) of Sand in Hole (SI-SF)	
SV: Vol. of Hole (SJ/SC)	
SW: Dry Mass (Wt.) of Material	
SDD: Dry Density (SW / SV)	
PR: Maximum Dry Dens. (TR 415 / TR 418)	
%PR: % Density (Sand) (SDD / PR) x 100	

NUCLEAR METHOD (TR 401) Nuclear Device No. ____	Test 1	Test 2	Test 3
DS: Density Standard Count			
DC: Density Test Count			
DR: Density Count Ratio (DC / DS)			
WD: Wet Density			
MS: Moisture Standard Count			
MC: Moisture Test Count			
MR: Moisture Count Ratio (MC / MS)			
M: Moisture by Mass (Wt.)			
MP: Moisture by Percent - *TR 401* ☐ / *TR 403* ☐			
NDD: Dry Density (WD - M) or $\frac{100 \times WD}{100 + MP}$			
%NPR: % Density (NDD / PR) x 100			
ADD: Average Dry Density (NDD) or (NDD/3)			
PR: Maximum Dry Density (TR 415 / TR 418)	1949		
%PR: % Dens.(Nuclear) (% NPR) or (% NPR/3)			

Remarks ____

Inspector ____ (Nuclear Film Badge No.) ____ *(Signature)*

Figure A-2 (Metric)
Density & Moisture Content Worksheet - Front (03-22-0750)

Pulverization, P_1 and P_2 (TR 431)					
* Test No. * *Utilize as many columns as necessary per test section.*		1	2	3	4
Adjusted Wet Mass (Wt) Sample (A)					
Mass (Wt) of + 19 mm (3/4 in) Material (B_1)					
Mass (Wt) of + 4.75 mm (No. 4) Material (B_2)					
% Pulverization 19 mm (3/4 in) (P_1)	$100 \times \frac{(A - B_1)}{A}$				
% Pulverization 4.75 mm (No. 4) (P_2)	$100 \times \frac{A - (B_1 + B_2)}{A}$				

Field Moisture Content at Compaction, % FM (TR 403)					
* Test No. * *Utilize as many columns as necessary per test section.*		1	2	3	4
Total Wet Mass (Wt) of Matl. at Compaction (A)					
Total Dry Mass (Wt) of Matl. at Compaction (B)					
Mass (Wt) of Water (C)	$(A - B)$				
% Field Moisture Content (% FM)	$100 \times \frac{C}{B}$				

Optimum Moisture and Maximum Dry Density Adjustments for Material Containing 20% - 60 % Siliceous Aggregate (TR 415)				
		1	2	3
Optimum % Moist. of Tot. Material, (OM)	$OM = [(\frac{100 - c}{100}) \times om] + \frac{c}{100}$	9.8		
Maximum Dry Density, lb/ft³ (PR) *(English)*	$PR = \frac{160 \times pr \times z}{\frac{c}{100} \times pr \times z + [160 \times (1 - \frac{c}{100})]}$			
Maximum Dry Density, kg/m³ (PR) *(Metric)*	$PR = \frac{2564 \times pr \times z}{\frac{c}{100} \times pr \times z + [2564 \times (1 - \frac{c}{100})]}$	1949		

Figure A-2 (Metric)
Density & Moisture Content Worksheet - Back (03-22-0750)

Method of Test
FIELD MOISTURE - DENSITY RELATIONSHIPS
DOTD Designation: TR 415 - 99
METRIC VERSION

METHOD B - DETERMINATION BY FIELD CURVE

I. Scope

A. This test procedure is designed to determine the optimum moisture and maximum dry density of material based on a curve developed from field-condition material. The procedure is applicable to all soils and soil aggregates with or without cement or lime additive, including recycled in-place material. This method is to be used as permitted by DOTD TR 418 or the specifications.

Note B-1: *If the moisture contents are properly adjusted during the test to provide a minimum of one point on the wet side and two points on the dry side, maximum density and optimum moisture can be determined with three points by using the Zero Air Voids Line to establish the wet leg of the curve. Additional points will be necessary if the first three moisture contents do not result in two points on the dry side and one point on the wet.*

B. Reference Documents
1. TR 418 - Moisture-Density Relationships
2. TR 403 - Determination of Moisture Content
3. AASHTO M 92 - Wire Cloth Sieves for Testing Purposes
4. S 401 - Sampling Soils
5. DOTD TR 108 - Splitting and Quartering Samples

II. Apparatus

A. **Mold**
1. A cylindrical metal mold having a capacity of 0.00944 m^3 manufactured with an internal diameter of 101.60±0.41 mm and a height of 116.43±0.13 mm and with a detachable collar approximately 64 mm in height, which can be fastened firmly to a base plate.
2. Molds are to be replaced when any diameter is more than 102.21 mm or the height is less than 115.57 mm at any point.
3. A cylindrical metal mold, having a capacity of 0.002832 m^3, manufactured with an internal diameter of 152.46±0.66 mm and a height of 154.90±0.41 mm, and with a detachable collar approximately 89 mm in height, which can be fastened firmly to a base plate.
4. Molds shall be replaced if any diameter is more than 153.39 mm or the height is less than 152.40 mm at any point.
5. A cylindrical metal mold, having a capacity of 0.002124 m^3, manufactured with an internal diameter of 152.46±0.66 mm and a height of 116.43±0.13 mm, and with a detachable collar approximately 64 mm in height, which can be fastened firmly to a base plate.
6. Molds shall be replaced if any diameter is more than 153.39 mm or the height is less than 115.57 mm at any point.

Note B-2: *Different makes of compactive devices may use mold base plates of different designs. The mold base plate must be compatible with the make of the compactive device used.*

B. **Compactive device**
1. A metal 2.495±0.023 kg rammer with a circular striking face with a diameter of 50.80 ±0.025 mm and arranged to control the height of drop to 305 ±2 mm.
2. A metal 4.536 ±0.045 kg rammer, with a circular striking face with a diameter of 50.80 ±0.25 mm and arranged to control the height of drop to 457 ±2 mm (for use with 0.002832 m^3 mold only).

C. **Compaction block** - A uniform rigid foundation such as a stable block or pedestal composed of portland cement concrete with a smooth, level surface on the top and bottom, with both surfaces parallel, weighing a minimum of 90 kg. The compaction block may be obtained from the district laboratory.

D. **Straightedge** - steel straightedge, approximately 305 mm long.

E. **Balance or scale** - a balance having a capacity of 15 kg or more and sensitive to 5 g.

F. **Sieve** - a 4.75 mm sieve conforming to AASHTO Designation M 92

G. **Tools**
1. Mixing pans with appropriate covers
2. Shovel
3. Spoons
4. Pointed trowel
5. Spatula or large suitable mechanical device for thoroughly mixing the soil with water
6. Large screwdriver to remove material from mold
7. Graduated cylinder (optional)
8. Scalping screen - 25 mm brass sieve or box screen

H. **Water**
I. **Sealable containers** - capable of holding required quantity of material (e.g., 4-L cans with friction top lids)
J. **Laboratory Curve**
K. **Density and Moisture Content Worksheet** (03-22-0750) Figure B-1.
L. **Field Compaction Report** - (03-22-4193) Figure B-2
M. **Engineer's Curve** - Alvin 1010-21 or equivalent

III. Sample: Processed material in field condition.

A. When the aggregate retained on the 4.75 mm sieve is 5% or greater, obtain a representative sample of 35 kg of material In accordance with S-401. Obtain the sample from the roadway after blending of soil and additive (if applicable) prior to compaction.
B. When the aggregate retained on the 4.75 mm sieve is less than 5%, obtain a representative sample of 15 kg of material in accordance with S-401. Obtain the sample from the roadway after blending of soil and additive (if applicable) prior to compaction.
C. Thoroughly mix the material.
D. In accordance with TR 108, split the mixed sample into five reasonably equal sized representative portions. Seal the representative portions in separate containers that will prevent moisture loss.

IV. Procedure

A. Select one of the representative portions. Squeeze a handful of material in the palm of your hand and analyze the moisture content in terms of the following.
   1. Material forms a cake which will bear very careful handling without breaking - material is at least 3 - 5% below optimum moisture.
   2. Material just dampens the hand when squeezed - material is near or at optimum moisture.
   3. Material leaves visible moisture on the hand when squeezed - material is above optimum moisture. For the purpose of this test, the material should be approximately 2 - 3% above optimum.
B. Adjust the moisture content of the representative portions until three portions meet each of the moisture conditions shown in Steps A. 1 - 3, using the following methods. Reseal each portion in its container. Set the remaining portions aside.
   1. Air-drying - Spread the representative portion into a pan and stir it as often as possible during the drying period.

Note B-3: *Under some weather conditions (e.g., low temperature, high humidity), it may be necessary to use the procedure for drying material in TR 403 to dry the material to a suitable moisture content. If this method is used, take care not to dry the material beyond the point needed to perform this test. Do not dry to constant mass.*

   2. Increase moisture content - Place a representative portion into another pan. Determine the mass of the representative portion. In accordance with **Step V. A.**, calculate the amount of water required to increase the moisture content of the material approximately 2 - 3%. Add sufficient water to increase the moisture content of the material in increments of approximately 2 - 3%.

Note B-4: *The actual quantity of water needed will depend on the gradation and initial moisture content of the representative portion.*

C. Select the correct size mold.
   1. If the percent retained on 4.75 mm sieve is less than 5, select the 0.000944 m^3 mold.
   2. If the percent retained on the 4.75 mm sieve is 5 or greater, select the 0.002832 m^3 mold.
D. Mold the representative portions.
   1. Attach base plate to mold. Determine the mass of the mold and base plate and record as **e** on the worksheet.
   2. Attach the collar to the mold to complete the mold assembly, and place the mold on the compaction block.
   3. Open the container of one representative portion and thoroughly mix the material.
   4. Place a quantity of the material in the mold in an even layer that will yield slightly more than 1/3 the volume of the mold after compaction. Remove and discard any material larger than 25 mm in diameter (e.g., aggregate, RAP, clumps of previously stabilized materials), and any trash (e.g., bottle caps, pavement markers, pieces of concrete, steel, etc.). Reseal the container.
   5. Use a pointed trowel to rearrange particles, filling voids in the loose material without compacting the material, to a uniform lift thickness.
   6. Rest the rammer on top of the layer to be compacted. Compact the layer.
      a. When using the 0.000944 m^3 mold, use 25 blows per layer with the 2.495 kg rammer from a 305 mm drop.

b. When using the 0.002832 m^3 mold, use 75 blows per layer with the 2.495 kg rammer from a 305 mm drop or 28 blows per layer with the 4.536 kg rammer from a 457 mm drop.

7. Note the height of the compacted material. If the compacted layer is not 1/3 the height of the mold, correct for any deviation by adjusting the quantity of material used for the subsequent layer.
8. Repeat **Steps IV. D. 1 - 7** for two more layers.
9. After the third layer has been compacted, place the mold assembly and compacted specimen in a pan.
10. Tap the collar with the straightedge to loosen material bond. Remove the collar from the mold, without twisting or causing shear stress to the molded specimen.
11. Note the height of the compacted test specimen.
    a. If the compacted material is greater than 7 mm above the top of the mold (for the 0.000944 m^3 mold) or 14 mm (for the 0.002832 m^3 mold), remix it with the original material and repeat the test.
    b. If the compacted material is below the rim of the mold, remove all the material from the mold, remix it with the original material and repeat the test.
12. Keeping the mold, base plate, and specimen in the pan, trim the specimen even with the top of the mold, using the straightedge. Fill any depressions formed during trimming with the trimmed material. After the depressions are filled, smooth the top of the cylinder with the straightedge even with the top of the mold.
13. Determine the mass of the mold, base plate, and specimen and record as **d** on the worksheet.
14. Determine the wet density of the specimen in accordance with **Step V.B**. Record as g" on the worksheet.
15. Detach the base plate from the mold. Remove the specimen from the mold.
16. Take a moisture sample from the center of the compacted specimen. Determine the wet mass, dry mass, mass of water, and moisture content of the test specimen in accordance with DOTD TR 403. Record on the worksheet as **h**, **I**, **j**, and **k** (respectively).
17. Determine the dry density of each specimen in accordance with **Step V.C**.
18. Plot the point on the Field Compaction Report, representing the intersection of a horizontal line projected from the dry densities and a vertical line projected from the moisture contents.
19. Open the container for the second representative portion and thoroughly mix the material.
20. Mold this material in accordance with **Steps D. 1 - 18**.
21. Thoroughly mix the third representative portion. Mold this material in accordance with **Steps D. 1 - 18**.

E. Develop a moisture-density curve.
   1. Draw a line parallel to the Zero Air Voids Line through the point with the highest moisture content.
   2. Draw a line through the other two points, intersecting the line drawn in **Step 1**.
   3. Evaluate the two lines in terms of the following
      a. Ensure that a minimum of three points meet the conditions in **Step IV. A**.
      b. No point falls to the right of the Zero Air Voids Line. Any point that falls to the right of the Zero Air Voids Line is not valid and must be rerun.
   4. If the above conditions are met, round the peak of the curve, as closely as possible to the intersection, to form a smooth continuous line.
   5. If all above conditions are not met, run additional representative portions in accordance with **Steps IV.D.1 - 18** until these conditions are met.
   6. Determine the Optimum Moisture Content, %. The Optimum Moisture Content is the moisture content corresponding to the peak of the Dry Density Curve.
   7. Determine the Maximum Dry Density. The Maximum Dry Density is the dry density of the soil at the optimum moisture content.

V. Calculations

A. Use the following formula to calculate the quantity of water needed to increase the moisture content of the representative portion by approximately 2 - 3%, as needed.

$$C = A \times B$$

where:

C = approximate qty. of water to be added, g
A = wet mass of representative portion, g
B = water to be added, decimal

example:

A = 2300 g
B = 0.02

$$C = 2300 \times 0.02$$

$$C = 46 \text{ g}$$

Note B-5: *If the technician prefers to measure water, instead of determining its mass, one mL of water is equal to one gram of water.*

example: 46 mL = 46 g

B. Calculate the wet density of each test specimen.

1. Calculate the wet mass of compacted soil to the nearest gram using the following formula.

$$f = d - e$$

where:

f = wet mass of compacted soil
d = mass of mold, base plate, and specimen, g
e = mass of mold and base plate

example:

d = 6128 g
e = 4227 g

$$f = 6128 - 4227$$

$$f = 1901\ g$$

2. Calculate the wet density of each specimen to the nearest kg/m³ using the following formulas.

For the 0.00944 m^3 mold: $g = f \div 0.944$
For the 0.002833 m^3 mold: $g = f \div 2.832$
For the 0.002124 m^3 mold: $g = f \div 2.124$

where:

g = wet density of the specimen, kg/m^3
f = wet mass of compacted soil, g
0.944, 2.832 & 2.124 = constants, representing the reciprocal of the volumes of the molds, m^3

example:

f = 19.01 g

$$g = \frac{f}{0.944}$$

$$g = \frac{1901}{0.944}$$

$$g = 2013.77$$

$$g = 2014\ kg/m^3$$

C. Calculate the dry density to the nearest 1 kg/m^3 using the following formula.

$$I = \frac{100 \times g}{100 + k}$$

where:

I = dry density, kg/m^3
g = wet density of specimen, kg/m^3
k = moisture content, %
100 = constant, converts to decimals

example:

g = 2014 kg/m^3
k = 15.2 %

$$I = \frac{100 \times 2014}{100 + 15.2}$$

$$I = \frac{201400}{115.2}$$

$$I = 1748.26 = 1748$$

VI. Report

Report optimum moisture (OM) and maximum dry density (PR).

VII. Normal Test Reporting Time

Normal testing and reporting time is two hours.

MATT MENU SELECTION - 07

Louisiana Department of Transportation and Development

DENSITY & MOISTURE CONTENT WORK SHEET

DOTD 03-22-0750
Metric/ English
Rev. 9/98

Metric/English (M or E) M *(Entry Field Located on Menu)*

Project No. ______ **Date Tested** ______ **Material Code** ______
Submitted By ______ **Purpose Code** ______ **Spec. Code** ______
Test Method ___ *N = Nuclear S = Sand Cone* **Item Number** ______
Station Tested ______ + ______ **Section & Test No.** ______

Location: ______ Lift No: ______ Depth of Test: ______

OM:	Optimum % Moisture Content of Total Material TR 415 or TR 418)	OM	16.3
%FM:	Field % Moisture Content at Compaction (TR 403) *(See back for calculations)*	%FM	
P_1:	% Pulverization 19mm (3/4" SIEVE) (TR 431) *(See back for calculations)*	P_1	
P_2:	% Pulverization 4.75mm (NO.4 SIEVE) (TR 431) *(See back for calculations)*	P_2	

(TR 415) Cross Reference Test No.	Sta. No.:		**Max. Dry Density Method** 2 *(1 = TR 415 A 2 = TR 415 B 3 = TR 418)*
a: Total Wet Mass (Wt.) of Sample			
b: Mass (Wt.) of +4.75 (+4) Material			
c: % By Mass (Wt.) of 4.75 (+4)Retained (100 b/a)			
d: Mass (Wt.) of Mold & Soil	6128	6051	6130
e: Mass (Wt.) of Mold	4227	4232	4227
f: Mass (Wt.) of Compacted Soil (d - e)	1901	1819	1903
g: Wet Density (f / 0.944) or (f / 2.832) or (f / 2.124) (f x 30) or (f x 10) or (f / 0.075)	2014	1927	2016
h: Mass (Wt.) of Wet Soil	621	630	635
i: Mass (Wt.) of Dry Soil	539	558	535
j: Mass (Wt.) of Water (h - i)	82	72	100
k: % Moisture Content (100 j/i) (TR 403)	15.2	12.9	18.7
l: Dry Density 100g / (100 + k)	1748	1707	1698

om *(from Family of Curves)*: ______ pr *(from Family of Curves)*: ______ FAMILY OF CURVES ZONE NUMBER ___

SAND METHOD (TR 401)	
SA: Mass (Wt.) of Sand in Mold	
SB: Vol. of Mold	
SC: Unit Mass (Wt.) of Sand (SA/SB)	
SD: Orig. Mass (Wt.) of Sand	
SE: Final Mass (Wt.) of Sand	
SF: Mass (Wt.) of Sand in Cone (SD-SE)	
SG: Orig. Mass (Wt.) of Sand	
SH: Final Mass (Wt.) of Sand	
SI: Mass (Wt) of Sand in Cone & Hole (SG-SH)	
SJ: Mass (Wt.) of Sand in Hole (SI-SF)	
SV: Vol. of Hole (SJ/SC)	
SW: Dry Mass (Wt.) of Material	
SDD: Dry Density (SW / SV)	
PR: Maximum Dry Dens. (TR 415 / TR 418)	
%PR: % Density (Sand) (SDD / PR) x 100	

NUCLEAR METHOD (TR 401) Nuclear Device No. ____	Test 1	Test 2	Test 3
DS: Density Standard Count			
DC: Density Test Count			
DR: Density Count Ratio (DC / DS)			
WD: Wet Density			
MS: Moisture Standard Count			
MC: Moisture Test Count			
MR: Moisture Count Ratio (MC / MS)			
M: Moisture by Mass (Wt.)			
MP: Moisture by Percent - *TR 401* ☐ / *TR 403* ☐			
NDD: Dry Density (WD - M) or $\frac{100 \times WD}{100 + MP}$			
%NPR: % Density (NDD / PR) x 100			
ADD: Average Dry Density (NDD) or (NDD/3)			
PR: Maximum Dry Density TR 415 TR 418)	1760		
%PR: % Dens.(Nuclear) (% NPR) or (% NPR/3)			

Remarks ______

Inspector ______ (Nuclear Film Badge No.) ______ *(Signature)*

Density and Moisture Content Worksheet (03-22-0750)
Figure B-1 (Metric)

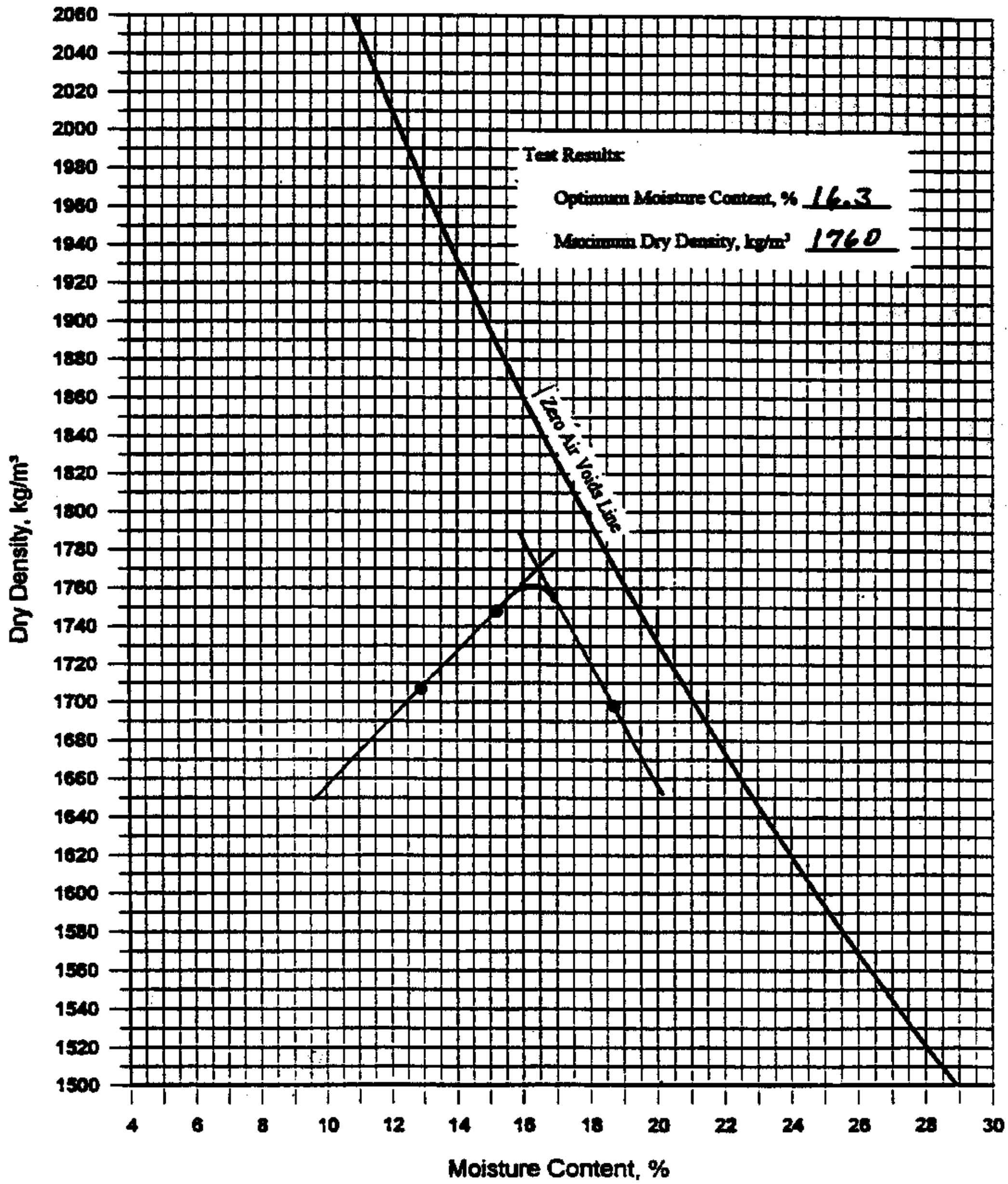
DOTD 03-22-4193
Metric
8/98

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

DOTD TR 415 METHOD B - METRIC
FIELD COMPACTION CURVE

Project No: ____________________ Station No: ____________________

Sample No: ____________________ Date: ____________________



Field Compaction Report - (03-22-4193)
Figure B-2 (Metric)